

*THE LIVING LEGACY OF THE HARVARD
PIGEON LAB: QUANTITATIVE ANALYSIS IN
THE WIDE WORLD*

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From the Harvard Pigeon Lab of the 1960s arose a behavior-analytic approach that was quantitative and rigorous, rooted in Herrnstein's matching law. Researchers modified the matching law to describe choice behavior in a variety of different settings and examined its relations with other quantitative models. Beginning in the early 1970s, researchers began using the Harvard Pigeon Lab's quantitative framework to study in the laboratory specific aspects of the world outside the laboratory. Much of this work concerned investigations of self-control—choice of a larger, more delayed reinforcer over a smaller, less delayed reinforcer. Experiments using a quantitative framework derived from the matching law have also been conducted outside the laboratory; however, these have been far less frequent. Current and future researchers will benefit the field by devising new, creative ways to investigate the matching law and related quantitative models outside the laboratory. Such research can help to demonstrate the validity of these models as basic principles of behavior, can enhance public opinion of and rewards for such research, and can stimulate further development of the Harvard Pigeon Lab's quantitative approach by using that approach with new variables.

Key words: choice, matching law, quantitative models, humans, pigeons, rats

The Harvard Pigeon Lab championed a specific kind of psychology research—a rigorous, quantitative analysis of behavior. Most readers of this journal are familiar with the work being done in laboratories around the world that has been closely derived from work done in the Pigeon Lab. Perhaps not as familiar, however, is how research derived from this work has been and can be applied to understanding the world outside the laboratory. It is this latter aspect of the Pigeon Lab's legacy that I will focus on in the present paper.

To put this discussion of the applications of Pigeon Lab research into context, a brief review of the possible usefulness of these applications may be helpful. First, if the principles of behavior elucidated in the Pigeon Lab are accurate, then these same principles should, in some form, also help us to understand behavior outside the laboratory. True, it is not possible to control conditions outside the laboratory as well as they can be controlled inside the laboratory, and this can make it difficult to investigate the principles of behavior outside the laboratory. The hu-

mans who participate in laboratory experiments are, however, the same humans who also live outside the laboratory, with the same genetic and experiential backgrounds. Thus the study of how humans behave inside the laboratory should, to at least some degree, help us to understand and modify how they behave outside the laboratory. Second, by showing how the Pigeon Lab research applies to the world outside the laboratory, both psychologists and nonpsychologists can be impressed by the power and usefulness of a quantitative, analytic approach. This can result, for example, in greater funding opportunities for research derived from the Pigeon Lab and in more students becoming interested in the field. Finally, expanding the Pigeon Lab research to new settings containing novel stimuli may stimulate new ideas for experiments and models concerning the principles of behavior.

Given all of these benefits of applying the Pigeon Lab research to the world outside the laboratory, one might expect to find extensive evidence of such applications. Indeed there is an extremely large literature concerning clinical applications specifically designed to modify the behavior of a target person or persons. Many examples of this type of research can be found within the pages of the *Journal of Applied Behavior Analysis*. Basic research using Pigeon Lab models in the

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world outside the laboratory is, however, quite uncommon.

In this paper I will first briefly review the Pigeon Lab's quantitative modeling milestones in recent decades. Second, I will discuss some of the Pigeon Lab procedures that presaged specific outside-the-laboratory research or that deliberately attempted to simulate outside-the-laboratory conditions. Finally, I will describe some of the basic and applied research conducted outside the laboratory that has been directly related to models or principles of behavior developed in the Harvard Pigeon Lab.

The Harvard Pigeon Lab produced a large amount of research each year for several decades. To keep the present paper's length within reasonable bounds, and also because I believe that quantitative modeling was the Pigeon Lab's greatest contribution, I will limit the research described in this paper to research that has been specifically based on the quantitative models or principles of choice developed in the Pigeon Lab. My primary goal in this paper is to show how the laboratory's quantitative approach can help us to understand our everyday lives.

THE HARVARD PIGEON LAB'S QUANTITATIVE MILESTONES

Perhaps the first significant milestone in the development of the Harvard Pigeon Lab's quantitative analysis of behavior was Herrnstein's (1961) publication of the first version of what came to be known as Herrnstein's matching law. Additional information about the matching law was published by Herrnstein in 1970 and 1974. The matching law is a quantitative model expressing how animals—human as well as nonhuman—distribute their choices among various alternatives. The matching law states that animals match the distribution of their choices to the distribution of the reinforcers for those choices. In equation form:

$$\frac{B_1}{B_2} = \frac{R_1}{R_2}, \quad (1)$$

in which B_i represents the number of choices of response alternative i , and R_i represents the number of reinforcers for responses on alternative i . In Equation 1, if there are two alternatives, 1 and 2, and responses for Alter-

native 1 result in reinforcers twice as often as do responses on Alternative 2, then the animal should choose Alternative 1 twice as often as Alternative 2.

In one version of the matching law, only one response alternative appears in the equation, along with the reinforcers for responses on that alternative. All other possible reinforcers are subsumed into the variable R_e :

$$B_1 = \frac{kR_1}{R_1 + R_e}. \quad (2)$$

In this case the absolute rate of responding, B_1 , is measured. The parameter k is the asymptotic response rate that would occur if there were reinforcers only for B_1 , in other words, if R_e were equal to 0 (de Villiers, 1977).

Baum (1974b, 1979) described a modification of the matching law that came to be known as Baum's generalized matching law. This version added two free parameters to Equation 1: s_R (sensitivity to reinforcement) and k (response bias).

$$\frac{B_1}{B_2} = k \left(\frac{R_1}{R_2} \right)^{s_R}. \quad (3)$$

The parameter s_R expresses to what degree the behavior ratio changes as a function of the reinforcer ratio. If the behavior ratio changes to a greater degree than does the reinforcer ratio (e.g., if a threefold change in the reinforcer ratio results in a fourfold change in the behavior ratio), then the animal is said to overmatch and s_R will be greater than 1.0. In contrast, if the behavior ratio changes to a lesser degree than does the reinforcer ratio (e.g., if a threefold change in the reinforcer ratio results in a twofold change in the behavior ratio), then the animal is said to undermatch and s_R will be less than 1.0. If the behavior ratio changes to a similar degree as does the reinforcer ratio (e.g., if a threefold change in the reinforcer ratio results in a threefold change in the behavior ratio), then s_R will be equal to 1.0. Turning to k , if the animal shows a consistent preference for Alternative 1 over Alternative 2 regardless of the reinforcer ratio, k will be greater than 1.0. If there is no consistent preference for Alternative 1 or 2, then k will be equal to 1.0. Baum's generalized matching law allowed researchers to describe additional

types of systematic behavioral variation using a single quantitative model. Note that when both s_R and k are equal to 1.0, Equation 3 reduces to Equation 1.

There were many Harvard Pigeon Lab publications that proposed refinements to or elaborations of the matching law. These included treating delayed reinforcers and lesser amounts of reinforcers similarly to lower frequencies of reinforcers and vice versa, treating a higher quality reinforcer similarly to a greater amount of a reinforcer, and measuring responding as both discrete responses and as time spent responding (see, e.g., Baum & Rachlin, 1969; Chung & Herrnstein, 1967; Miller, 1976).

Beginning in the 1970s, the literature arising out of the Harvard Pigeon Laboratory began to reflect what was to be an enduring controversy: whether the matching law or alternative maximization models better describe behavior (see, e.g., Herrnstein & Heyman, 1979; Herrnstein & Loveland, 1975; Herrnstein & Vaughan, 1980). This controversy has never been resolved definitively, but it has been the impetus for much intriguing research regarding the control of behavior.

Very quickly after the inception of the matching law, current and former Pigeon Lab researchers, as well as others, began using the matching law as a means for understanding or developing other quantitative models that have some properties similar to the matching law. Examples of quantitative models involved in such investigations are signal-detection theory, delay-reduction theory, and economic theory (Davison & Tustin, 1978; McCarthy & Davison, 1981; Rachlin, Green, Kagel, & Battalio, 1976; Squires & Fantino, 1971).

Methodological advances were also made. For instance, Mazur's 1987 chapter from the Harvard Symposium series was the first publication to describe the adjusting procedure, an extremely useful methodological technique for investigating and developing quantitative models derived from Harvard Pigeon Lab research. This technique is used when the reinforcers available from two alternatives differ with regard to more than one variable, for example, reinforcer amount and reinforcer delay. During the adjusting procedure, researchers adjust one variable (e.g., the delay of the reinforcers available for responding on

an alternative) until the subject's responses are indifferent between the two response alternatives. This procedure allows researchers to measure quantitatively to what degree a subject values specific aspects of a reinforcer.

The preceding is an extremely brief, and not at all comprehensive, review of some of the major milestones in the quantitative modeling approach that arose from the Harvard Pigeon Lab, centered around the matching law. Excellent comprehensive reviews of the early matching law literature can be found in de Villiers (1977), Davison and McCarthy (1988), and Williams (1988).

OUTSIDE INSIDE: LABORATORY SIMULATIONS OF THE WORLD OUTSIDE

Harvard Pigeon Lab researchers began pushing the bounds of their quantitative investigations almost as soon as the matching law was first formulated. They wanted to understand under what environmental conditions their models would hold. These environmental conditions included ones that more closely simulated the world outside the laboratory than was the case with traditional laboratory paradigms.

One of the first researchers to take such an approach was Baum. As early as 1972 he published an experiment that examined the matching law in a pigeon that lived continuously inside the experimental chamber. The usual procedure was to test pigeons (or rats) for 0.5 to 1 hr per day in an experimental chamber, with the subjects living in their home cages the rest of the time. This often meant that the subjects did not receive all of their food during the experimental sessions, possibly modifying the effects of the experiment's independent variables on the subjects' choices for food during the experiment. Baum's pigeon's choice behavior closely conformed to matching, thus demonstrating that matching was not somehow due to subjects spending limited amounts of time in the experimental chambers. Baum's experiment was critical in helping to convince some researchers that matching is a principle of behavior endemic to the subject, rather than a creation of the experimental procedure.

Baum (1974a) took this line of research one step further with his study of the match-

ing law in wild pigeons. The pigeons lived in the attic of his house, exiting and entering via an opening to the outside. Baum placed an experimental apparatus in his attic on which any of the flock could respond between outside foraging trips. The choice behavior of the flock closely conformed to matching. This experiment used a traditional laboratory apparatus. There were many conditions not found in the laboratory, however: The pigeons were wild, they were not confined by the experimenter to the area containing the apparatus, and the apparatus recorded the combined responses of many pigeons. Thus this experiment consisted of a rare combination of laboratory and nonlaboratory elements.

More recently, Baum has extended his analysis of the matching law to describe group choice behavior to humans. He and Kraft originally investigated in pigeons the relations among group choice behavior, the matching law, and models derived from optimal foraging theory, and then later extended this research to humans (Baum & Kraft, 1998; Kraft & Baum, 2001). Baum was also one of the first to publish any sort of experiment on the matching law using human subjects (Baum, 1975), a methodological step that certainly brought us closer to understanding how the matching law might apply to our daily lives.

Another attempt by Harvard Pigeon Lab researchers to investigate conditions more similar to those present outside the laboratory was Miller and Loveland's (1974) matching law research in which the subjects (pigeons) chose among five alternatives. In the world outside the laboratory, animals usually have more than two choices. Miller and Loveland found that the matching law described well the pigeons' choices of the five alternatives.

A large research literature, with many clinical applications, has developed out of Harvard Pigeon Lab researchers' attempts to conduct basic research on self-control, defined as choice of a larger, more delayed reinforcer over a smaller, less delayed reinforcer. The opposite is defined as impulsiveness. The first publication on self-control using a Pigeon Lab quantitative framework was by Rachlin and Green (1972). They showed that pigeons are not likely to demonstrate self-control, and

that this behavior is consistent with a version of the matching law:

$$\frac{B_1}{B_2} = \frac{A_1 D_2}{A_2 D_1}, \quad (4)$$

in which A_i and D_i represent the reinforcer amounts and delays, respectively. Rachlin and Green showed that pigeons were more likely to show self-control if they were given a chance to commit to this choice ahead of time (see also Ainslie, 1974). Ainslie (1975) described in detail how the matching law could help to explain self-control and impulsiveness. Mazur and I published the results of experiments demonstrating that pigeons could be trained to show self-control that was still present after an 11-month hiatus from the experimental chamber, and we examined some of the parameters that made that training successful (Logue & Mazur, 1981; Mazur & Logue, 1978). This was followed by research showing that the generalized matching law could be used to describe training-induced individual differences in self-control (Logue, Rodriguez, Peña-Correal, & Mauro, 1984):

$$\frac{B_1}{B_2} = k \left(\frac{A_1}{A_2} \right)^{s_A} \left(\frac{D_1}{D_2} \right)^{s_D}. \quad (5)$$

This equation suggests that animals, including humans, are less likely to show self-control the more sensitive they are to the delay of reinforcement and the less sensitive they are to the amount of reinforcement, that is, the greater the value of s_D and the smaller the value of s_A . The variable s_D can also be described as representing the degree to which delayed reinforcement is discounted—how much less delayed reinforcement is worth than immediate reinforcement.

Together, these attempts to bring the world outside the laboratory into the laboratory prepared the way for a large number of possible applications of the matching law. These applications have included using the matching law both to gain a basic understanding of nonlaboratory behavior and to help modify the behavior of humans and other animals outside the laboratory.

APPLICATIONS IN THE WORLD OUTSIDE THE LABORATORY

Nonclinical research specifically applying the matching law to the world outside the laboratory has not been extensive, and what little there is has mostly been conducted within the context of the self-control paradigm. Nonlaboratory, non-self-control, basic research investigating choice behavior within the context of the matching law has been relatively rare, despite several published statements delineating the benefits of such research (see McDowell, 1988; Vuchinich, 1995; Vuchinich & Tucker, 1988).

An early example of such research is an experiment concerning the behavior of people in small groups (Conger & Killeen, 1974). In this research 5 college students sat, one at a time, at a table with three confederates of the experimenters. The job of the confederate seated directly across from the participant was to keep the conversation going. The job of the two confederates on either side of the participant was to state orally their approval of the participant's statements. One of these two confederates, however, made these statements much more frequently than did the other. The relative amount of time that the participants spent talking to the confederates on either side of them matched the relative frequency of the statements of approval by those confederates. Thus, the matching law was able to describe an important aspect of the social behavior of a member of a group of people. Beardsley and McDowell (1992) published a similar experiment more recently, although their experiment focused on the single-alternative form of the matching law (Equation 2, as opposed to Equation 1). Individual college students talked to an experimenter who verbally reinforced the students' statements according to variable-interval schedules of reinforcement. Thus, in this experiment there was a single source of reinforcement. The dependent variable was the amount of time a student spent looking at the experimenter.

Several experiments have examined the conformity of students' behavior to the matching law. For example, Mace and Neef (1994) demonstrated that adolescents distribute their time working on two stacks of math-

ematics problems in accordance with the generalized matching law (Equation 3). Martens, Lochner, and Kelly (1992) showed that the time spent by fourth graders in attending to academic tasks as a function of praise was described well by the single-alternative form of the matching law (Equation 2). Shriver and Kramer (1997) demonstrated that the generalized matching law (Equation 3), with teacher behavior as the reinforcer and child behavior as the measured response, described well the classroom behavior of 2 first-grade children. Related research has been conducted using children diagnosed with attention deficit hyperactivity disorder (ADHD). The frequency with which these children completed mathematics problems as a function of reinforcement with tokens, and the relative frequency with which they worked on one or another computer task as a function of the opportunity to play Nintendo, conformed well to the single-alternative form of the matching law (Equation 2) and the generalized matching law (Equation 3), respectively (Kollins, Lane, & Shapiro, 1997; Murray & Kollins, 2000).

Goltz (1999) conducted an experiment using very different types of subjects and choices. Goltz asked adult participants to make many different business decisions about where to invest their funds. For example, a participant might have to decide repeatedly to which of two divisions of a company the participant would allocate research and development funds. Goltz showed that the relative frequency with which a participant chose one or the other alternative for investment closely conformed to the generalized matching law.

A most intriguing attempt to investigate the matching law in the world outside the laboratory is that described in an article by Vollmer and Bourret (2000). These researchers examined whether the matching law would describe the frequency with which both male and female Division I basketball players took two- as opposed to three-point shots. The players' shot choices seemed to conform well to the matching law. It is not clear, however, that the reinforcement for these shots (i.e., getting the ball in the basket) followed a variable-interval, as opposed to a variable-ratio, reinforcement schedule, which complicates the predictions of Equation 1.

As noted above, by far the greatest number of applications of the matching law to situations similar to the world outside the laboratory have involved situations that could be described as involving self-control and impulsiveness (Equations 4 and 5). These investigations have involved a wide variety of human behavior. For example, Rachlin, Siegel, and Cross (1994) used the self-control version of the matching law to help to understand why some people play lotteries. Petry and Casarella (1999) showed that discounting of delayed money is greater, and thus impulsiveness is more likely, in people who are gamblers or substance abusers than in people who are not. Green and his colleagues have examined the effects of age and inflation on choices between smaller, more immediate and larger, more delayed amounts of money. Their results show, for example, that older adults (senior citizens) discount delayed money less than do college students, and that college students discount delayed money less than do sixth-grade children (Green, Fry, & Myerson, 1994; Green, Myerson, Lichtman, Rosen, & Fry, 1996; Green, Myerson, & Ostaszewski, 1999; Ostaszewski, Green, & Myerson, 1998).

Healthy and nonhealthy behavior have also been a focus of self-control applications of the matching law (Logue, 1997, 2000; Simpson & Vuchinich, 2000). Much of this work has revolved around attempts to understand under what conditions people will choose to experience a drug such as heroin, nicotine, or alcohol, which may be immediately reinforcing but may damage their health in the long run (Bickel, Odum, & Madden, 1999; Kirby, Petry, & Bickel, 1999; Madden, Petry, Badger, & Bickel, 1997; Mitchell, 1999; Petry, Bickel, & Arnett, 1998; Petry & Casarella, 1999; Vuchinich & Simpson, 1998, 1999). Logue et al. (1992) showed that injecting rats with cocaine decreased self-control, the first of many experiments demonstrating the effects of drugs on self-control from a matching law perspective. Odum, Madden, Badger, and Bickel (2000) showed that heroin abusers who were more likely to say that they would share needles also discounted delayed money greater than did non-needle-sharing heroin abusers. In other words, heroin abusers who said they would share needles appeared less likely to show self-control for money than did

other heroin abusers. Both types of heroin abusers discounted delayed heroin more than delayed money; both types of heroin abusers appeared more likely to be impulsive for heroin than for money.

All of these experiments on drugs and self-control were conducted in laboratory settings, in attempts to simulate in the laboratory various aspects of the world outside the laboratory. Christensen-Szalanski (1984) instead examined the predictions of the matching law relating to preferences for events occurring outside the laboratory. More specifically, he asked women who had paid to enroll in a childbirth class to state their preferences for and against anesthesia for labor, which would alleviate immediate pain, but might not be as healthy for the baby or the mother in the long run. Thus, in this experiment, choosing anesthesia was defined as impulsiveness. Christensen-Szalanski showed that these women were less likely to state a preference for anesthesia prior to labor, and also 1 month postpartum, than during labor, preference changes that are predicted by Equation 4. In addition, preferences during labor were closely related to the women's actual decisions about whether or not to request anesthesia.

The self-control framework derived from the matching law has also been used to examine children who have been diagnosed with emotional disturbances or ADHD (Neef, Mace, & Shade, 1993; Sonuga-Barke, Taylor, Sembi, & Smith, 1992). For example, in Schweitzer and Sulzer-Azaroff's (1995) research, 5- and 6-year-old boys with and without ADHD chose between self-control and impulsiveness. The reinforcers were nickels. The boys with ADHD were less likely to show self-control.

Although in 1985 Herrnstein published an elaborate explanation of the application to criminal behavior of the matching law framework of self-control (Wilson & Herrnstein, 1985), there has been little empirical investigation of Herrnstein's proposals. Some examples of research consistent with this application have, however, been published by Cherek and his colleagues (Cherek & Lane, 1999; Cherek, Moeller, Dougherty, & Rhoades, 1997). Cherek et al. showed that male parolees were more likely to be impulsive for money in the laboratory if they had a history of

violent behavior. Cherek and Lane's subsequent experiment indicated that treating men with a history of conduct disorder and aggression using a drug that enhances the neurotransmitter serotonin increased these men's self-control and decreased their aggression.

Using a different population, Anderson and I investigated self-control and impulsiveness in higher education administrators (Logue, 1998; Logue & Anderson, 2001). We showed that, with greater administrative experience, these administrators are more likely to state that they would be impulsive for money promised for their units by their supervisors. Over time, administrators may learn that they are unlikely to receive promised, delayed funds for their units, so they choose immediate funds, even if the immediate funds are smaller in amount than the promised, delayed funds.

Even though I have reported a large number of studies in this section, especially studies concerning self-control, the great majority of them were conducted in the laboratory, albeit with deliberate attempts to simulate the world outside the laboratory. Further, of those conducted outside a traditional laboratory, almost all have involved choices between hypothetical, as opposed to actual, reinforcers. There has been little quantitative analysis of actual behavior outside the laboratory, despite there being many opportunities to do so (Critchfield & Kollins, 2001; Fisher & Mazur, 1997; Logue, 1995; Myerson & Hale, 1984).

CONCLUSION

In this paper I have tried to demonstrate the contributions that the Harvard Pigeon Lab has made to research and practice outside the traditional laboratory, with an emphasis on helping us to understand our (and other species') everyday behavior. Such research can validate our belief in the general principles of behavior that we discover in the laboratory, can demonstrate to a wide audience the importance of a quantitative behavior-analytic approach, with consequent increased numbers of students and grant funding, and can help to generate new ideas for experiments and models.

The experiments reviewed here demon-

strate that there is not a clear distinction between the worlds outside and inside the laboratory. Nonhuman subjects in the laboratory can be used to simulate conditions seen usually with humans outside the laboratory, a variety of conditions can be investigated in the laboratory using human subjects, and experiments can be conducted outside the laboratory (Mace, 1994). All of these different types of approaches can be useful in helping us to understand how quantitative principles of behavior apply to our everyday lives.

Unfortunately, research that speaks directly to the world outside the laboratory has been limited, with the exception of some clinical settings. There are many areas still ripe for investigation. For example, why not examine, within the quantitative framework of the matching law, the tendency to save or spend money given changes in overall level of income and expenses? Another example might be shoppers' trips to one of two aisles of a grocery store as a function of the frequency of free samples of food in those two aisles. Still another example might be the frequency of visiting one of two doctors depending on the pleasantness of the visit, which might be a function of such variables as the demeanor of the receptionist, the length of time spent waiting for the doctor, and the cost of the visit. And why has no one yet investigated people's choices among adjacent slot machines that pay off according to differing schedules of reinforcement? These are just a few ideas among many possibilities. Using the matching law to understand and predict better how people behave in these situations may assist us in finding new ways to help people prepare for their retirements financially, control their overeating, visit doctors when needed, and decrease their gambling.

I would like to issue a challenge to current and future researchers to find new, creative ways to investigate, outside the laboratory, the quantitative models arising from the Harvard Pigeon Lab. The origins of the Harvard Pigeon Lab are intimately tied to the work of B. F. Skinner, whose presence was felt there until his death in 1990. Skinner was always thinking about how what he saw in the laboratory could be applied outside the laboratory, and vice versa, as exemplified by his provocative books such as *Walden Two* (1948), *Science and Human Behavior* (1953), and *Be-*

yond *Freedom and Dignity* (1971). He used his laboratory knowledge to help him construct an optimal environment for his baby daughter, to construct teaching machines, and to devise better guided missiles. The researchers—as opposed to the clinicians—who have followed in his theoretical footsteps, however, have very often focused on tight, and then tighter, and then even tighter control of variables in the laboratory. There is no question that such research is extremely important to our understanding of the principles of behavior. It should not be, however, the only type of research being conducted. There are a great many benefits to an outside-the-laboratory, empirical approach.

The Harvard Pigeon Lab is physically gone. However, it lives on, not only in other laboratories but in the research that has been done, and will be done, outside the laboratory.

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